

NOTE CONCERNING THE PERIOD OF THE QUASI-BIENNIAL OSCILLATION

J. K. ANGELL, J. KORSHOVER, AND T. H. CARPENTER

Environmental Science Services Administration, Washington, D.C.

ABSTRACT

The period of the quasi-biennial oscillation is examined through the use of a harmonic procedure which allows one to examine periods of interest without omission of any data. On the basis of 8, and $5\frac{1}{2}$ years, of mean-monthly zonal-wind and temperature data in the Northern and Southern Hemispheres, respectively, it is found that: (1) A quasi-biennial oscillation in zonal-wind exists in the troposphere of the Tropics and subtropics; (2) The temperate-latitude stratosphere is the seat of a surprisingly strong temperature oscillation of approximately 24-mon. period, with some stations in the western Pacific exhibiting a biennial oscillation larger than the annual oscillation; (3) In temperate and low-polar latitudes of the Northern Hemisphere stratosphere the predominant period of zonal-wind oscillation exceeds 30 mon., while in the Southern Hemisphere there is more evidence for a 26-28-mon. periodicity, thus suggesting an asymmetry between hemispheres. Inasmuch as these results imply that at some latitudes the quasi-biennial oscillation is truly a biennial oscillation, care should be exercised in eliminating possible causes for the oscillation on the basis of the 25 or 26-mon. periodicity noted in the tropical stratosphere.

1. INTRODUCTION

The mean period of the quasi-biennial oscillation has generally been placed at 25 to 27 mon., based mainly on autocorrelation and simple spectral analyses of tropical stratospheric data [1], [2], [3]. Inasmuch as the possible causes of this oscillation depend rather critically upon the mean period, it was deemed worthwhile to make a more detailed analysis of the period of oscillation than has yet been made, at least to the authors' knowledge. To this end, a type of spectral analysis somewhat similar to that used by Probert-Jones [4] has been applied to mean-monthly zonal-wind and temperature data obtained in the stratosphere and troposphere for stations in the tropical, temperate, and polar latitudes of both hemispheres. The period of record utilized extends from January 1956 through December 1963 for the Northern Hemisphere stations and from July 1957 through December 1962 for the Southern Hemisphere stations.

2. PROCEDURES

The study of the quasi-biennial oscillation has always been hampered by the limited extent of the data record. This drawback is accentuated if one uses conventional harmonic (or spectral) analysis techniques to obtain estimates of the relative importance of periodicities comprising the total fluctuation. For example, with a data record of 8 yr., one could determine harmonic amplitudes at periods of 96, 48, 32, 24 mon., etc., but the amplitude at a period of 26 mon. could be obtained only by omission of 18 mon. of the record and determination of the third harmonic of 78 mon. of data. This problem is avoided by

the use of non-orthogonal functions through the medium of partial correlations and three-dimensional regression techniques. Thus, if we let $X_1 = \sin 2\pi f_1 t$ and $X_2 = \cos 2\pi f_2 t$ (where f_i is any frequency and t is time) then a percentage measure of how much of the variance of the observed data, X_3 , is given by X_1 and X_2 is

$$(R_{3,21})^2 = \frac{(r_{31})^2 + (r_{32})^2 - 2r_{31}r_{32}r_{12}}{1 - (r_{12})^2} \quad (1)$$

where the r 's with subscripts represent conventional, partial correlation coefficients. In order to determine the phase and amplitude of any particular periodicity, we note, following Panofsky and Brier [5], that the equation for the corresponding plane of regression is

$$X_3 = A + BX_1 + CX_2$$

where the three coefficients may be evaluated through solution of the "normal" equations

$$\begin{aligned} NA + B\sum X_1 + C\sum X_2 &= \sum X_3 \\ A\sum X_1 + B\sum X_1^2 + C\sum X_1X_2 &= \sum X_1X_3 \\ A\sum X_2 + B\sum X_1X_2 + C\sum X_2^2 &= \sum X_2X_3. \end{aligned} \quad (3)$$

Moreover, since the plane of regression passes through the mean of X_1 , X_2 and X_3 , the above three equations may be reduced to the two equations

$$\begin{aligned} B\overline{X_1^2} + C\overline{X_1X_2} &= \overline{X_1X_3} \\ B\overline{X_1X_2} + C\overline{X_2^2} &= \overline{X_2X_3} \end{aligned} \quad (4)$$

whence, by Cramer's Rule (solution by determinant)

$$B = \frac{\overline{X_1 X_3} \cdot \overline{X_2^2} - \overline{X_2 X_3} \cdot \overline{X_1 X_2}}{\overline{X_1^2 X_2^2} - \overline{X_1 X_2} \cdot \overline{X_1 X_2}}$$

$$C = \frac{\overline{X_1^2} \cdot \overline{X_2 X_3} - \overline{X_1 X_2} \cdot \overline{X_1 X_3}}{\overline{X_1^2 X_2^2} - \overline{X_1 X_2} \cdot \overline{X_1 X_2}} \quad (5)$$

The amplitude of the periodicity is given by $(B^2 + C^2)^{1/2}$ and the phase by $\tan^{-1} (B/C)$. In this manner, the contribution of any particular periodicity to the total fluctuation may be determined based on all available data, but it might be noted that, whereas this procedure can be carried out relatively easily by computer, it would be very laborious to carry out by hand.

In order to make the information so obtained more meaningful, at 2-mon. intervals between the periods of 40 and 14 mon. we have formed the ratio of the variances at these periods to the annual variance, and then determined the square root. Thus, what is plotted in subsequent diagrams, in effect, is the ratio of the harmonic amplitude at a given period of oscillation to the harmonic amplitude of the annual oscillation. The resulting amplitude ratios have been smoothed by a 1-2-1 weighting in order to reduce the fluctuations in amplitude ratio at periods near the annual. Finally, in order to simplify the diagrams, the results obtained at 25(30) and 50 mb. have been averaged to provide a "stratospheric" mean and the results obtained at 300 and 500 mb. have been averaged to provide a "tropospheric" mean.

3. THE ZONAL-WIND PERIODICITY

Figure 1 shows the zonal-wind amplitude ratio in stratosphere and troposphere for stations located equatorward of 30°. In the stratosphere, all stations equatorward of the Tropic of Cancer, with the exception of San Juan, yield a maximum amplitude ratio at a period very close to 25 mon. The slightly smaller period of oscillation at San Juan suggests that subtle longitudinal variations in periodicity do occur, most likely as a result of the relatively short data record. It is interesting, and probably significant, that the 25-mon. periodicity begins to break down near the Tropic of Cancer, with both Marcus and Midway yielding maximum amplitude ratios at periods slightly less than 24 mon. and slightly more than 30 mon. This same tendency is noted at San Diego and Quintero (fig. 2). The double periodicity appears, in this case, to represent the superposition of the 25-mon. tropical periodicity with the longer-term zonal-wind periodicity noted particularly in the temperate latitudes of the Northern Hemisphere (see discussion in connection with fig. 2). The anomalous behavior of the Southern Hemisphere station of Antofagasta is indicated in passing, but no explanation is offered therefor.

In the troposphere an oscillation of 25-26 mon. period shows up clearly at Canton, and similar oscillations can

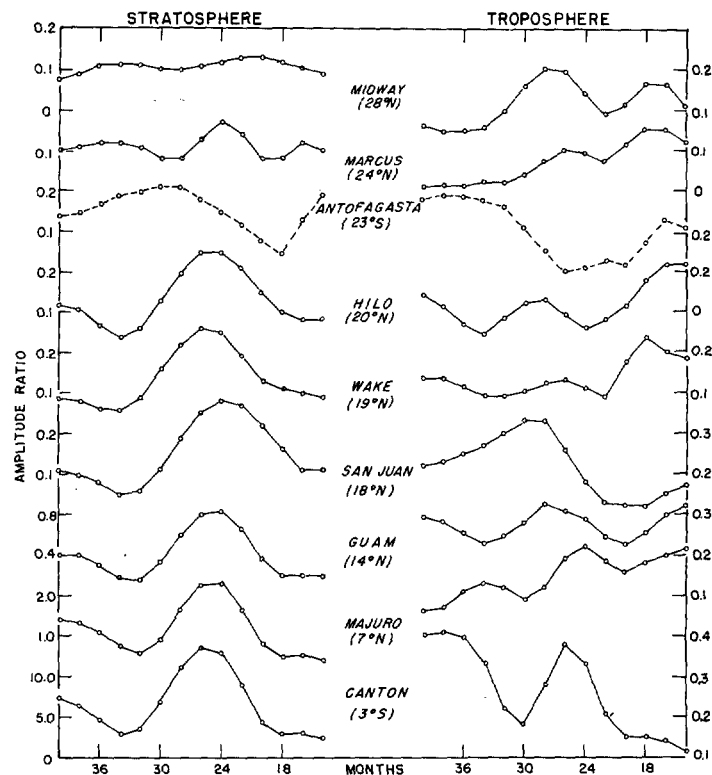


FIGURE 1.—Ratio of the harmonic amplitude of the mean-monthly zonal wind (at given periods of oscillation) to the annual amplitude for periods of oscillation ranging from 40 mon. to 14 mon. and for stations equatorward of 30°. The "stratosphere" data represent the average of 25(30) and 50-mb. amplitude ratios, the "troposphere" data the average of 300 and 500-mb. amplitude ratios. The solid line indicates an analysis based upon a period of record of 8 yr., the dashed line an analysis based upon a period of record of 5½ yr.

be noted at all other stations equatorward of 30° (except Antofagasta) even though the period varies considerably. At Marcus and Midway a double periodicity shows up also in the troposphere, but at a somewhat different period than in the stratosphere. Thus, while it is apparent that the situation becomes quite confused near latitude 30°, it is reasonable to state that a quasi-biennial variation in mean-monthly zonal wind does occur in the tropical and subtropical troposphere.

Figure 2 shows the zonal-wind amplitude ratio for stations located between 30° and 60°. In the stratosphere at these latitudes there is little evidence for a quasi-biennial periodicity, but rather, the amplitude ratio tends to be a maximum at a period exceeding 30 mon., with a suggestion of a longitudinal variation in this relatively long-period oscillation based on the periods noted at Tateno and Sapporo in comparison with these noted at Oakland and Olympia. Inasmuch as the Southern Hemisphere station of Puerto Montt appears somewhat anomalous in exhibiting a zonal-wind periodicity near 24 mon., the same analysis was performed upon the New Zealand stations of Auckland (37°S.) and Invercargill

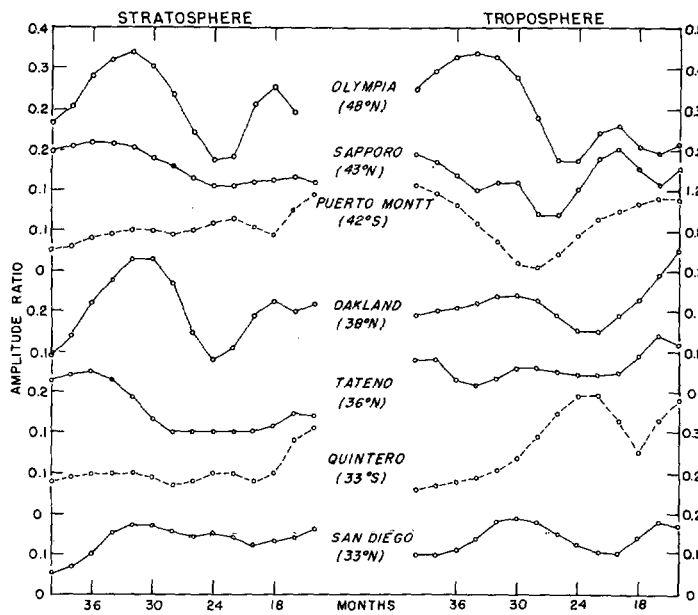


FIGURE 2.—Same as figure 1, but for stations between latitudes 30° and 60°.

(46°S.). These stations (not plotted in fig. 2) exhibit quite pronounced zonal-wind oscillations of period 26 and 28 mon., respectively, with amplitude ratios in the stratosphere of 0.40 in the case of Auckland and 0.24 in the case of Invercargill. The interesting question that now arises is to what extent the longer-period, zonal-wind oscillation in the temperate latitudes of the Northern Hemisphere is related to the quasi-biennial oscillation both in the Tropics and (apparently) in the temperate latitudes of the Southern Hemisphere. Is the quasi-biennial oscillation in the Northern Hemisphere masked by "noise" induced, perhaps, by a non-uniform surface, or is the periodicity of 30 mon. or more simply a quasi-biennial oscillation in distorted form? If the latter is the case, the indiscriminate use of a particular harmonic period (for example 26 mon.) will lead to serious errors in phase-comparison estimates in the Northern Hemisphere.

In the troposphere of the middle latitudes the amplitude ratios vary quite chaotically, although all stations except the Southern Hemisphere stations exhibit a tendency for a periodicity between 28 and 34 mon., in general agreement with the periodicity found in the stratosphere. Thus, it is not unreasonable to state that the longer-term periodicity, whatever it may represent, shows up in the troposphere, as well as in the stratosphere.

Figure 3 shows the zonal-wind amplitude ratio for stations located poleward of 60°. In the stratosphere most of the stations exhibit the relatively long-period oscillation noted in the middle latitudes of the Northern Hemisphere. However, the two stations nearest the pole, Amundsen-Scott and Eureka, yield a periodicity close to that found in the Tropics. If this shift in period is real,

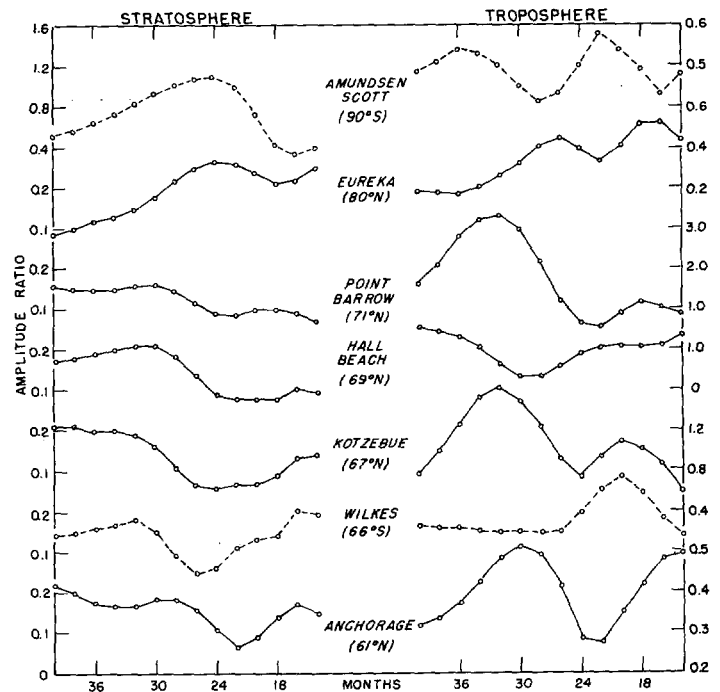


FIGURE 3.—Same as figure 1, but for stations poleward of latitude 60°.

it is strange that none of the stations has a double maximum for the amplitude ratio, as was noted for the subtropical stations. Worthy of emphasis is the observation that in the stratosphere above Amundsen-Scott, the quasi-biennial zonal-wind oscillation is of greater amplitude than the annual oscillation.

In the troposphere of the polar latitudes the zonal-wind amplitude ratios vary erratically. The three Alaskan stations exhibit a periodicity of slightly more than 30 mon., but such a periodicity is not at all obvious at the other stations. On the basis of these data it appears unwise to generalize about possible periodicities in the polar troposphere.

4. TEMPERATURE PERIODICITY

Figure 4 shows the temperature amplitude ratio in stratosphere and troposphere for stations located equatorward of 30°. In the stratosphere all stations exhibit a maximum in the amplitude ratio at periods between 23 and 27 mon., but the periodicity is not as pronounced nor as uniform as in the case of the zonal wind. This is in agreement with the historical fact that the quasi-biennial oscillation was noted first in the zonal wind rather than in the temperature. At San Juan, Wake, Hilo, Antofagasta, and Marcus the peak ratios occur at a period close to 24 mon. One also notes with interest that Antofagasta fits in very well with the Northern Hemisphere stations when temperature is considered,

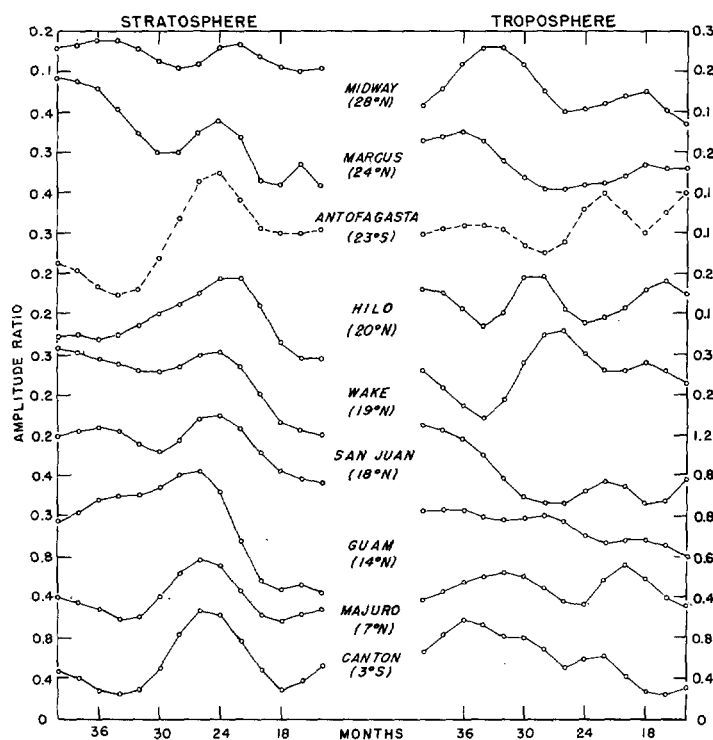


FIGURE 4.—Ratio of the harmonic amplitude of mean-monthly temperature (at given periods of oscillation) to the annual amplitude for stations equatorward of 30°. Otherwise, please see legend for figure 1.

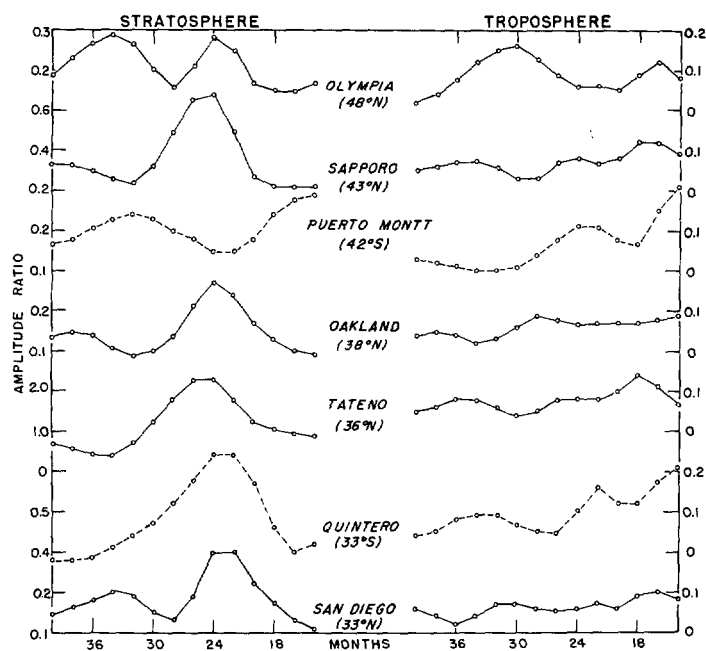


FIGURE 5.—Same as figure 4, but for stations between latitudes 30° and 60°.

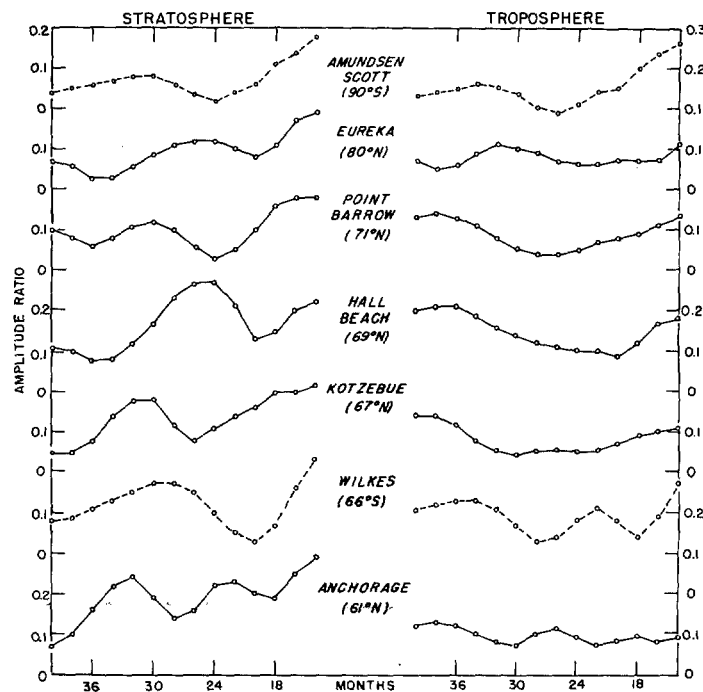


FIGURE 6.—Same as figure 4, but for stations poleward of latitude 60°.

while it fitted in poorly when zonal wind was considered. This raises some doubts concerning the representativeness of the South American winds at high levels.

In the troposphere the situation is not clear cut. Stations such as Canton, Majuro, San Juan, and Quintero have peaks in the amplitude ratio at periods of 20 or 22 mon. However, Wake and Hilo have peaks at a period of 27 and 29 mon., respectively. Thus, while we hesitate to say that a quasi-biennial temperature oscillation cannot be found in the tropical troposphere, it certainly is not as evident as the quasi-biennial oscillation in zonal wind.

Figure 5 shows the temperature amplitude ratio for stations located between 30° and 60°. One of the more interesting features of the present analysis involves the evidence for a biennial variation in temperature in the stratosphere throughout this latitude band, with only Puerto Montt failing to exhibit a pronounced periodicity of 23 to 25 mon. At least in the Northern Hemisphere this is in complete contradiction to the zonal-wind results. Moreover, the fact that Marcus, Midway, and San Diego yield a double periodicity for both temperature and zonal wind argues against the double periodicity representing a superposition of separate periodicities in tropical and temperate latitudes. The 24-mon. periodicity also shows up extremely well at the New Zealand stations (not shown in fig. 5), with the appropriate amplitude ratio approximately 1.0 at Auckland and 0.5 at Invercargill. When one notes, in addition, that the amplitude ratio exceeds 2.0 at Tateo and 0.6 at Sapporo, there is strong evidence

for an anomalously large biennial variation in temperature in the temperate latitudes of the western Pacific. While the apparent difference in periodicity between zonal wind and temperature in the temperate latitudes of the Northern Hemisphere is unexplained at this time, it should be pointed out that both Puerto Montt and Olympia yield a maximum in the temperature amplitude ratio also at periods exceeding 30 mon., and these maxima appear to be associated with the maxima found for the zonal wind throughout this latitude band. It is as if the transition from quasi-biennial oscillation to relatively long-period oscillation was taking place nearer to the Pole in the case of the temperature than in the case of the zonal wind.

In the troposphere there is some slight evidence for a quasi-biennial oscillation in temperature, particularly in the Southern Hemisphere, as shown by the maximum in amplitude ratio at 22 mon. at Quintero and 23 mon. at Puerto Montt. San Diego, Tateno, and Sapporo also exhibit minor peaks at these periods.

Figure 6 shows the temperature amplitude ratio for stations located poleward of 60°. In the stratosphere, Anchorage exhibits the double maximum in amplitude ratio found at Olympia (and San Diego and Midway). Otherwise, the Alaskan and Southern Hemisphere stations yield a maximum amplitude ratio at a period of about 30 mon., while the Candian stations of Eureka and Hall Beach yield a maximum at a period near 25 mon. This lack of consistency is distressing and makes generalization for these latitudes impossible.

In the troposphere there is evidence for a quasi-biennial oscillation only at Anchorage and Wilkes. With the exception of these two stations the amplitude ratio tends to be a minimum near the biennial period.

5. CONCLUSION

There is no doubt that the period of record utilized herein is relatively short for a detailed analysis of this nature, and some of the anomalies may be due to such a limited period. Furthermore, an analysis of this type could well be applied to many more stations so as to increase the reliability of the results. However, it is neces-

sary to start somewhere and it is believed that, despite these limitations, it has been demonstrated that a quasi-biennial zonal-wind oscillation exists in the troposphere of the Tropics and subtropics and that a surprisingly pronounced biennial temperature oscillation exists in the stratosphere of temperate latitudes. A problem worthy of further investigation involves the relatively long-period oscillation of the zonal wind in the temperate latitudes of the Northern Hemisphere, and of the zonal wind and temperature in polar latitudes generally, and the relationship of this periodicity to the quasi-biennial periodicity. Finally, since the period of variation of the temperature in the temperate stratosphere is so very close to the biennial, care should be exercised in deleting causes for the quasi-biennial oscillation on the basis of period alone. This would apply particularly to the phenomenon of subharmonic response, whereby a system oscillates at a multiple of the forcing period. The results presented here suggest that subharmonic response should be looked at more closely as a possible cause for the quasi-biennial oscillation.

ACKNOWLEDGMENTS

We wish to thank E. Farkas for providing us with upper-air data from New Zealand.

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[Received November 9, 1965; revised January 7, 1966]